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# A Data Acquisition and Analysis System for Nondestructive Testing of Wire Rope

By Todd M. Ruff

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Bruce Babbitt, Secretary

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## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | |
|---|---|---|---|
| ft | foot | MB | megabyte |
| ft/min | foot per minute | mV | millivolt |
| Hz | hertz | pct | percent |
| in | inch | s | second |
| kHz | kilohertz | V | volt |

# A DATA ACQUISITION AND ANALYSIS SYSTEM FOR NONDESTRUCTIVE TESTING OF WIRE ROPE

By Todd M. Ruff[1]

## ABSTRACT

Current methods of inspecting wire rope for broken wires or excessive wear include visual inspection, physical measurements of rope diameter, and electromagnetic nondestructive testing (NDT). Visual inspection and physical measurement are the least comprehensive methods. Electromagnetic NDT enables a more thorough assessment of the condition of a wire rope, but the repeatability, accuracy, and objectivity of this method can be improved. One means of achieving this goal is to use a computer to analyze the test data and determine the condition of the wire rope, including the presence of broken wires and corrosion, and the amount of wear. An off-the-shelf data acquisition and analysis system was tested in a U.S. Bureau of Mines laboratory using a continuous loop of wire rope containing fabricated flaws. The test rope was run through a commercially available NDT instrument. The output of the instrument, normally connected to a paper strip chart recorder, was digitized and analyzed with a personal computer. These initial tests were successful in showing that the use of a computer can improve current methods of NDT waveform collection and analysis.

[1]Electrical engineer, Spokane Research Center, U.S. Bureau of Mines, Spokane, WA.

## INTRODUCTION

Wire rope is widely used in underground mining operations for hoisting workers, materials, and ore. Despite mandatory rope inspections required by the Mine Safety and Health Administration (MSHA) to identify and retire damaged ropes, failures do occur. These rope failures may result in human injury or death, large losses in mine production, and substantial damage to the mine's shaft and hoisting equipment. The U.S. Bureau of Mines has worked with MSHA and the Canada Centre for Mineral and Energy Technology (CANMET) through cooperative research to improve wire rope inspection.

Current methods of inspecting wire rope for broken wires or excessive wear include visual inspection, measurements of rope diameter, and electromagnetic NDT. The first two methods are the least comprehensive because they are tedious, and errors may occur when examining the long lengths of ropes used in mining. Also, these methods do not allow inspection of the interior of the rope. While current techniques of electromagnetic NDT inspection enable a more thorough assessment of the condition of wire rope, including inspection for broken wires, wear, and corrosion, its accuracy and repeatability have been questioned. An assessment of the rope still relies heavily on an inspector's ability and experience in interpreting the data. There is little agreement between inspecting companies on the methods of determining rope strength, the rate of strength loss, and the amount of remaining rope life from either visual appearance or NDT inspection; however, NDT methods provide the best available techniques for determining rope condition.

One solution to the problem of maintaining objectivity when analyzing NDT data is to use computers to collect data and assist in analysis. This report describes an initial study of an off-the-shelf data acquisition and analysis system that can be run on a personal computer (PC).

## BACKGROUND

Several instruments are available that use electromagnetic principles to determine if broken wires, excessive wear, or corrosion are present on the surface or interior of a wire rope. A typical instrument consists of an electronics console, a sensor head, and a means to record the test data (fig. 1). All instruments use some method of introducing a magnetic field in the wire rope when the rope passes through the sensor head. Sensors measure this magnetic field, and the output signal is amplified and conditioned. These data are then recorded on paper strip charts and/or cassette tapes. Some instruments also provide an audible warning if a flaw is sensed on the rope.

Methods of magnetizing the wire rope vary from instrument to instrument. New instruments use permanent, rare-earth magnets to saturate the rope with a magnetic field, while some older instruments use an alternating electric current. Flaws in a wire rope that can be detected include breaks in the individual wires of the rope, called localized faults (LF), and actual loss of metallic cross-sectional area (LMA) resulting from corrosion or wear.

The LF signal from a magnetized, broken wire can be detected as a fringing magnetic field that extends beyond the surface of the wire rope. This effect results from a property of a magnetic flux that causes magnetic lines of force to repel each other and spread out in wide curves. Electromagnetic NDT instruments use sensors mounted within the sensor head to detect these fringing fields as the LF signal (fig. 2).

To detect LMA, sensors measure the total flux contained in the rope as it passes through magnets in the sensor head (fig. 2). The detection of any changes is based on the principle that, at magnetic saturation, the magnetic flux within the rope is proportional to its cross-sectional area. In measuring both LF and LMA, the specific sensors used and their location within the sensor head vary with each instrument.

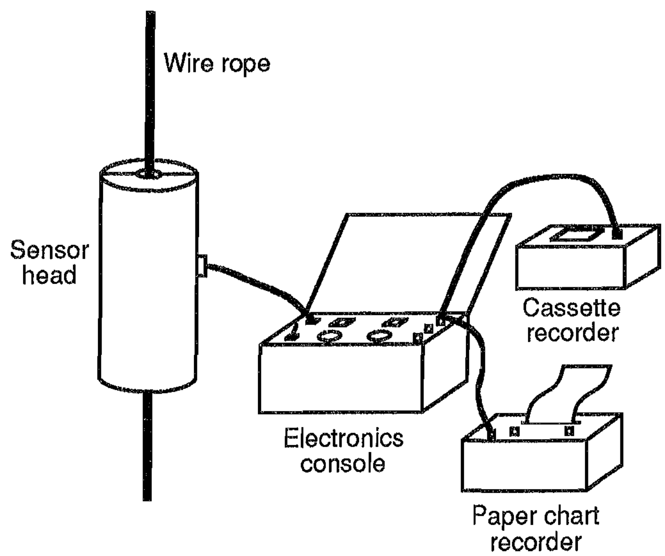


**Figure 1.—Components of NDT system for wire rope.**

In most cases, the LF and LMA signals are recorded on a paper strip chart. After running the entire length of a wire rope through an NDT instrument, the inspector examines this chart to locate broken wires, corrosion, and wear. A judgment is then made to determine if or when the wire rope must be retired by calculating the strength loss of the rope resulting from LMA and LF signals. Current regulations require that the rope be replaced if it has lost 10 pct of its original strength. However, NDT does not directly measure strength loss; at this point, much interpretation is required by the inspector.

A possible solution to eliminating variability resulting from inspector interpretation is to computerize data acquisition and analysis. Such a system could be used to determine the condition of a rope more objectively given specific field test data.

USBM researchers are evaluating an off-the-shelf data acquisition system that runs on a PC. An NDT instrument and a 3/4-in-diam wire rope test loop that continuously passes the rope through the instrument (fig. 3) were used to test the system. The test rope is 53 ft long and has gaps cut into an individual crown wire of one strand. The point at which the rope is connected to form a loop is referred to as the splice. The first gap cut into the rope is 4 ft from the end of the splice; subsequent gaps increase in length up to 64 in, but each is at least 30 in from adjacent gaps. A section of five crown wires, each 64 in long, was removed at the end of the loop. A full description of the test rope is shown in table 1.

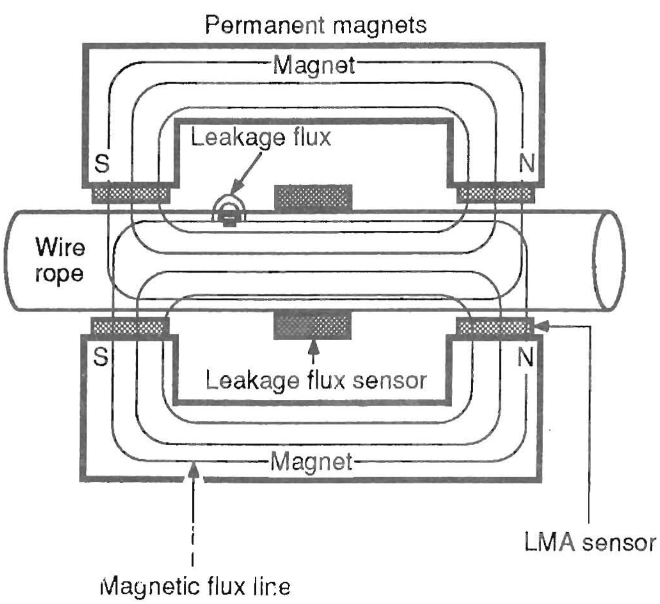


Figure 2.—Typical layout of sensor head.

**Table 1.—Test loop layout**

(NOTE: Rope is 3/4 in. in diameter, 6 × 25, fiber core, filler wire, right regular lay)

| Description | Length, in | Time of occurrence, s |
|---|---|---|
| Space | 48 | |
| Gap cut in wire | 1/16 | 1.5 |
| Space | 30 | |
| Gap | 1/8 | 1.8 |
| Space | 30 | |
| Gap | 1/4 | 2.2 |
| Space | 30 | |
| Gap | 1/2 | 2.6 |
| Space | 30 | |
| Gap | 1 | 3.0 |
| Space | 30 | |
| Gap | 2 | 3.3 |
| Space | 30 | |
| Gap | 4 | 3.7 |
| Space | 30 | |
| Gap | 8 | 4.2 |
| Space | 30 | |
| Gap | 16 | 4.6 - 4.8 |
| Space | 30 | |
| Gap | 32 | 5.3 - 5.6 |
| Space | 48 | |
| Gap | 64 | 6.2 - 7.0 |
| Space | 30 | |
| Five wires removed | 64 | 7.7 - 8.5 |
| Space | 48 | |
| Splice connection | 2 | 9.5 |

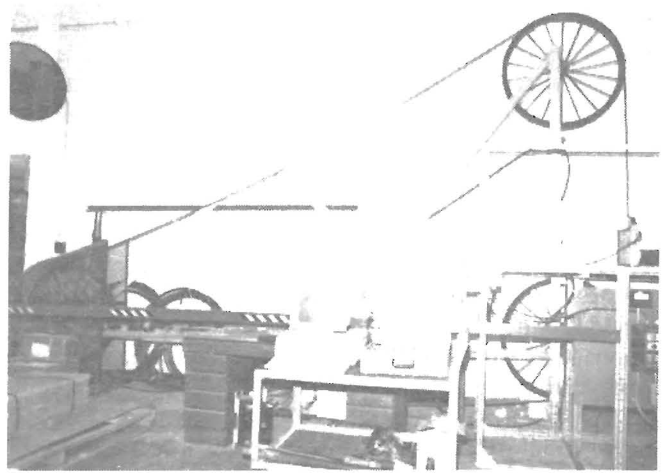

Figure 3.—Wire rope test loop at USBM facility.

# DESCRIPTION OF COMPUTER SYSTEM

The system for digitizing, storing, and analyzing the data from an NDT instrument consists of two main subsystems: the data acquisition system and the data analysis system.

## DATA ACQUISITION SYSTEM

The data acquisition system consists of the following equipment and software.

Computer:

A 386-based computer with 5.25-in and 3.5-in high-density drives.

1-MB RAM and 150-MB hard disk. The data acquisition system also runs successfully on an IBM XT[2] and an IBM AT.

Acquisition Board:

Metrabyte Dash-16F analog-digital expansion board.
Maximum throughput rate of 100 kHz.
16 single-ended or eight differential channels.
±10-V range, bipolar.
Configuration software - DAS-16, Rev. 4.00, by Metrabyte.

Acquisition Software:

Streamer, Rev. 3.10, Metrabyte.[3] This software allows digitized data from the DAS-16F board to be stored directly on a hard disk at sampling rates up to 60 kHz. The software uses a direct memory access (DMA) transfer to transfer data automatically from the input-output (I-O) board to the computer memory while the software is concurrently transferring data from the computer memory to the disk drive. This allows continuous high-speed data transfers for relatively long periods of time, depending on the disk memory size.

The output from the NDT instrument must be within the voltage range of the data acquisition board. This output is taken from the signal wires that provide the input for the paper chart recorder. The signal wires are connected to the data acquisition board using a 37-pin D-type connector. After making these connections, the procedure for acquiring data is as follows:

1. Optimize the hard disk to provide contiguous file space. Soft Logic Disk Optimizer software, version 4.0, is supplied with the Streamer software.

2. Create a file into which data are to be written. The Streamer software includes a "Make File" command.

   Command: MKFILE C:\<filename.ext> <size> /D.

File size is in kilobytes. /D provides diagnostics for the file. The file must exist in the root directory of the hard drive.

3. Start data acquisition.

   Command: STREAMER DAS16.

Fill in the menu parameters for the data acquisition run. The set-up screen is shown in figure 4. The acquisition is started by pressing F1 or F2. F2 writes a log file for documentation of the run. F10 is used to exit the program. The acquisition will automatically stop according to the duration set in the menu.

4. Unpack the binary file to an ASCII file.

   Command: UNPACK C:\<source file>, C:\<destination file>, <start-end>,/B.

The source file is the name of the Streamer data file and the destination file is the name of the ASCII file to be created. Start-End specifies the first and last data sample to be converted to ASCII. /B denotes bipolar data, i.e., data that range from -2048 to +2047 (± 10 V). /U denotes unipolar data ranging from 0 to +4095.

The data are now in a table format that can be viewed using any word processing or spreadsheet software.

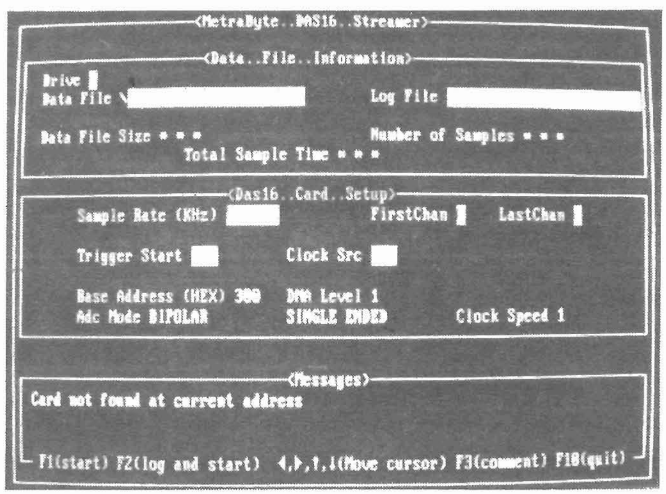


**Figure 4.—Set-up screen for Streamer data acquisition software.**

[2]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

[3]Metrabyte Corp. Streamer Software User Manual. Version 3.1, 1987, 28 pp.

## DATA ANALYSIS SYSTEM

Dadisp signal processing software by Digital Signal Processing (DSP) Development Corp. (version 2.01)[4] was chosen for this work. The software is a menu-driven data analysis program that works on the principle of graphics-based spreadsheets. The ASCII file created by Streamer can be imported into Dadisp using the import function. After the data are imported, they can be viewed graphically on the screen by creating a worksheet. Figure 5 shows a typical worksheet with two windows. Window 1 shows the original LF data of an NDT run, and window 2 shows the original LMA data. Figure 6 shows a four-window worksheet with the original waveforms in windows 1 and 2. Window 3 shows an overlay of the LF with the LMA data, and window 4 shows a portion of the LF data expanded. One worksheet can handle up to 64 windows, and there are over 200 functions for data transformation and analysis.

The following are just some of the operations available to enhance a signal's clarity or analyze its characteristics:

1. The signal can be expanded or compressed vertically or horizontally.
2. A cursor can be activated that displays the x and y coordinates as they move along the signal.
3. The signal can be differentiated or integrated.
4. The signal can undergo discrete or fast Fourier transformations (DFT, FFT) and power spectral density analysis.
5. The signal can be filtered.
6. Two signals can be cross correlated.
7. Background noise can be clipped from the waveform.
8. The waveform can be printed or plotted.

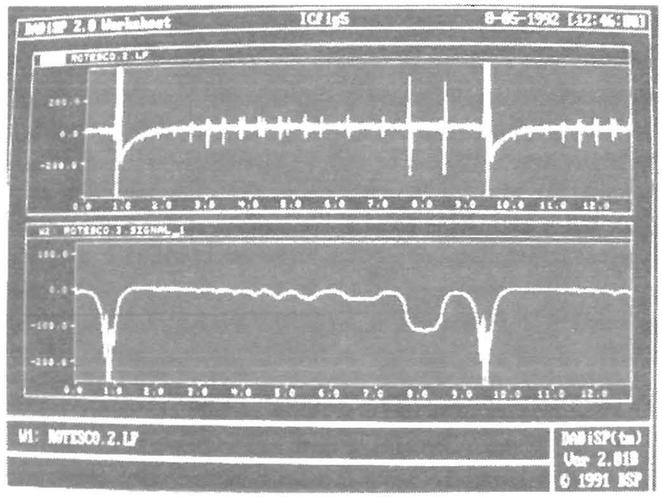

Figure 5.—Dadisp worksheet screen with LF and LMA signals.

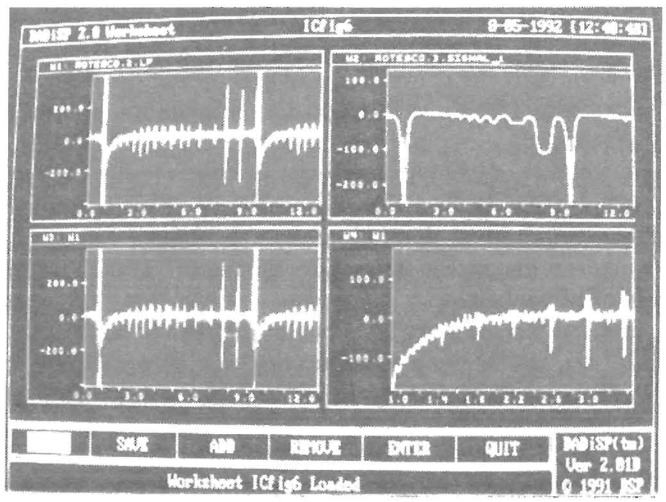

Figure 6.—Dadisp worksheet screen with analysis examples.

## TEST RESULTS

Several of the analytical tools available on Dadisp were evaluated using the NDT data acquired with the system (fig. 5). The tools selected had the potential to enhance the original data so that evaluation would be easier and results more consistent. Also, some of these tools were used to better understand the characteristics of the NDT data, such as frequency content.

The NDT data used in the evaluation are shown in figure 5. The top waveform is the LF signal and the bottom waveform is the LMA signal. The horizontal units on both the LF and the LMA signals are in seconds. It took approximately 9 s for the test rope to complete one pass through the NDT instrument. The vertical units are in digital counts (±2048), but this can be converted to volts by specifying the conversion in the input data file configured during the data import. In this case, each digital count corresponded to a voltage equal to the maximum input voltage divided by the maximum count value, or 4.88 mV per count.

Figure 7 shows the worksheet from figure 5 with the LF signal expanded to fill the screen. The vertical scale has also been expanded to make the signals from the gaps more prominent. Starting at the left side of the signal, the first large spike that goes off-scale at 0.8 s is the splice of the test rope. As the instrument recovers from this large

[4]DSP Development Corp. Dadisp Worksheet User Manual. Version 2.01, 1991, 160 pp.

disturbance, the signal ramps back to zero. At approximately 1.5 s, the first downward spike occurs, which corresponds to the 1/16-in-long gap cut in one wire. The next spike occurs at 1.8 s and is the signal from the 1/8-in gap. As the gap sizes increase, two spikes characterize one gap. For instance, the 64-in gap in the single wire shows the first spike at 6.2 s, which indicates the leading edge of the cut wire, and the second spike occurs at 7.0 s, which indicates the trailing edge. The test rope completes a cycle in 8.6 s, after which the signal from the splice occurs again.

Window 2 in figure 5 shows the LMA signal of the same test rope. Comparing window 1 and window 2 shows the correlation between the LF signal and the LMA signal. This comparison can be enhanced by overlaying the LF and LMA waveforms as shown in window 3 of figure 6. This could be important when evaluating field ropes and determining the correlation between LF and LMA. The first large disturbance in the LMA signal at 0.8 s is the splice. Gaps less than 1 in do not produce an obvious drop in metallic area. The decreases in area become larger as the gap size increases, and finally, the five 64-in-long removed wires produce the largest drop in metallic area. Determining the conversion and accuracy of the voltage as related to LMA and strength loss may be the subject of later work.

The LF and LMA signals shown were sampled at 2,000 samples per second for each channel. This was higher than required as determined by the Nyquist rate, which requires the sampling rate to be twice the highest frequency contained in the signal. The highest frequency found in preliminary tests of the LF signal was less than 100 Hz, so 200 samples per second would be sufficient for a rope speed of 400 ft/min. The LMA signal has lower frequency components than the LF.

To demonstrate theanalytical features of Dadisp, the power spectral density was calculated for a portion of the LF signal. Figure 8 shows the LF signal in window 1 and the power spectral density of a windowed portion of the signal in window 2. A Hamming window was used on the portion of the signal between sample numbers 6,000 and 12,000 (3 and 6 s, respectively). The power spectral density shows that most of the signal energy was contained between 0 and 40 Hz, and there were no frequency components above approximately 75 Hz. This confirms that relatively low sampling rates, greater than 200 samples per second, can be used for NDT data collection at rope speeds below 400 ft/min.

It is recommended that anti-aliasing filters be used to assure accurate digitized waveforms. This would prevent any signals with frequency content above the Nyquist rate from appearing on the digitized waveform as a signal at a lower frequency. This is particularly important when applying this type of system to field data. On these laboratory tests, the data were collected in a controlled environment and with known specimens, and no anti-aliasing was provided. Future work should include this precaution, however.

The last analysis feature evaluated was the differentiation of the LF waveform. The derivative was taken of a portion of the waveform to see if the signal from a broken wire could be enhanced and heightened above the background or rope noise. The premise was that the waveform from a broken wire would have a different and distinguishable slope when compared to the slope of the rope noise waveform. Differentiating the signal, however, did not prove this to be true, and no advantage was evident in performing the derivative analysis function.

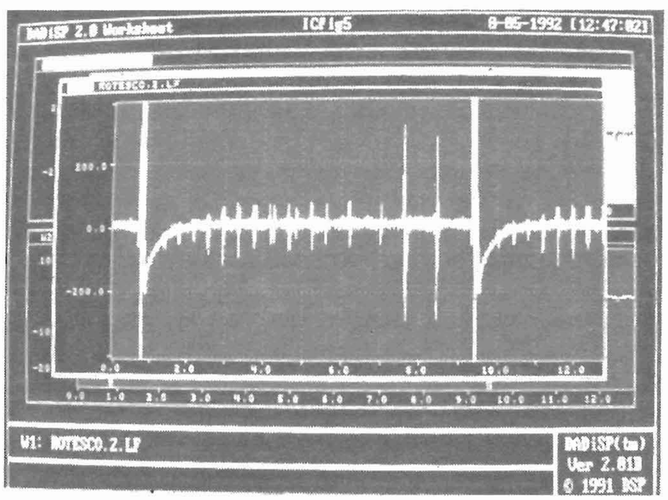


Figure 7.—LF signal expanded.

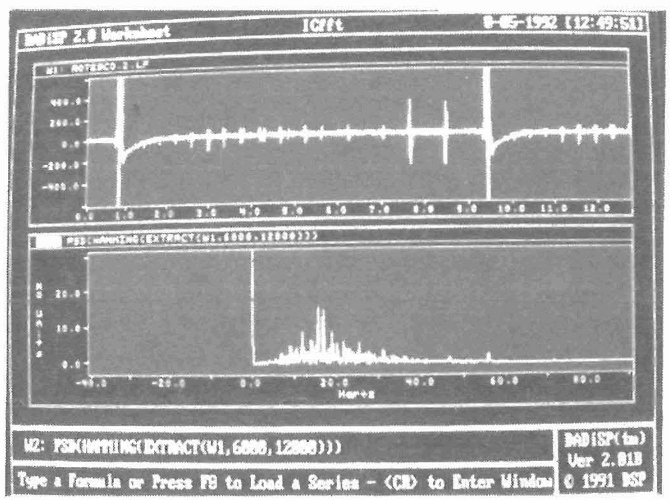


Figure 8.—Power spectral density of LF signal.

Many more analysis features are available with this software. Some of these features could be used to assist the NDT instrument operator in making a quantitative evaluation of the rope. For instance, a macro instruction could be developed in the software package to count broken wires or automatically calculate maximum strength loss in a rope on the basis of broken wires and LMA. A digital filter could also be designed to filter out rope noise. Further evaluation of the software is needed to perfect these operations.

## SUMMARY

The initial design of a computer-assisted method of analyzing data from electromagnetic NDT of wire rope has been completed. An off-the-shelf data acquisition and analysis system used with a PC proved successful in laboratory tests. An advantage to using such a system is the analytical capabilities gained. The waveforms generated can be evaluated with the software, and algorithms can be developed to count broken wires or measure LMA to make a general interpretation of the condition of the rope. This would eliminate total dependence on an instrument operator and the operator's interpretation of the waveforms.

Another advantage to using a computer for data collection would be the reduction in the bulk of the recording media. The data could be transferred to a floppy disk rather than to a paper strip chart. However, modifications to the current data collection system will be needed to make the system suitable for field use. An environmentally hardened laptop computer may be a solution.

Besides the immediately practical applications of the system, digitized data from wire rope NDT can be used in research to understand the basic characteristics of the waveforms and to evaluate methods of enhancing the information. The goal of this research is to improve current methods of determining when a wire rope should be retired. Repeatability and accuracy in making this determination are essential to the mining industry.

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